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Novel Fiber Grating Sensing Technique Based on the Torsion Beam*

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ABSTRACT

A novel fiber grating sensing technology based on the torsion beam is reported for the first time. The Bragg wavelength change is linear with the torsional angle and the torque. The fiber Bragg grating (FBG) is firmly mounted on the surface of the torsion beam with a determinate angle along the direction of the axes of the torsion beam. The range of the torsional angle is between -45° and +45° . The sensing sensitivity of the torsional angle is up to 11.534 degree/nm and that of the torque is up to 0.1595 Nm/nm, respectively. The formulas have been derived theoretically and the experimental results basically accord with the theoretical ones. This technology has many advantages, such as two directional tuning, the high sensitivity, the good repetitiveness and no chirping for the torsional angle within the range from -45° to +45° , etc. It has potential applications in the area of the fiber sensing, the fiber communication and laser technology.

Key words: Fiber Bragg grating, seansing technique, torsional beam, linear tuning.

1. INTRODUCTION

The fiber Bragg grating (FBG), which has many important advantages such as volume minuteness, compatibility with fiber system, collection frequency for wavelength and so forth, is attracting considerable subject for applications as fiber grating sensing technique in recent years[1]. A number of sensors, which are based on the detection of the wavelength shift $\Delta\lambda$ and the fiber Bragg grating are used as sensing elements, including both temperature and strain (or stress), have been reported[1,2]. The wavelength-encoded nature of the output of FBG element has many distinct advantages over direct intensity-based sensing schemes. Most importantly, as the sensed information is encoded directly into wavelength which is an absolute parameter, the output does not depend on the total light levels, losses in the connecting fibers and couplers, or source power.

In this paper, we reported a novel fiber grating sensing technology based on the torsion beam for the first time to our knowledge. The FBG is bonded to the surface of the torsion beam with a determinate angle along the direction of the axes of the torsion beam. The Bragg wavelength shift is linear to the torsional angle and the torque between -45° and +45° . The sensing sensitivity of the torsional angle is up to 11.534 degree/nm and that of the torque is up to 0.1595 Nm/nm, respectively. This technology has many advantages such as two directional tuning, the high sensitivity, the good repetitiveness and no chirping for the torsional angle within the range from -45° to +45°

2. PRINCIPLE

2.1. Analyses of Torsion Beam Strain

The analytic schematics of the torsion beam strain is shown in figure 1. A FBG is mounted on the surface of the torsion beam, l is the original grating length $\overline{\mathrm{QN}} = z_c$, L_0 and d are the length and the diameter of the torsion beam respectively, φ is the torsional angle. If the torsional strain of column beam is very small, we can consider this kind of twisting analysis to be a pure turn problem[3]. When the torque $\mathbf{M}_t$ is applied on the torsion beam, the produced stress will act on the FBG which is on the surface of the torsion beam no matter the torque $\mathbf{M}_t$ is along clockwise or not. Thus the torque $\mathbf{M}_t$ results in the change of grating period and refractive index.

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In order to obtain both longer and shorter wavelengths, the FBG should be bonded to the surface of the torsion beam with a determinate angle θ along the direction of the axes of the torsion beam. In principle, when the torque $\mathbf{M}_t$ is along contraclockwise, grating is stretched, the grating pitch becomes longer and the Bragg reflection wavelength becomes longer. In contrast, when the torque $\mathbf{M}_t$ is along clockwise, the grating is compressed, the pitch becomes shorter and the Bragg reflection wavelength becomes shorter. Therefore, if the torque $\mathbf{M}_t$ is applied on the torsion beam, it will be possible to infer the angle displacement or the torque by detecting the Bragg wavelength shift $\Delta\lambda$ of the sensor return.

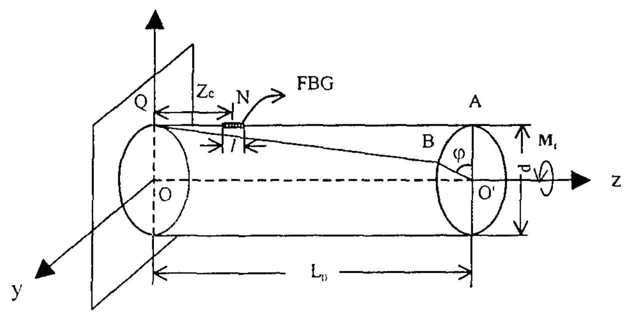

Fig.1 The analytic schematics of the torsion beam strain

From Fig. 1, the torsional strain of column beam γ can be expressed as

$$\gamma = \frac{d\varphi}{2L_0}, \tag{1}$$

the magnitude of the torque $\mathbf{M}_t$ is expressed by

$$M_t = GI_p \frac{\varphi}{L_0}, \tag{2}$$

where G is the modulus of the transverse elasticity of the torsion beam, and I_p is the inertia moment of cross section of the torsion beam. In our experiment, the ε of FBG due to the torque is approximately expressed by

$$\varepsilon = \frac{\Delta l}{l} \approx \frac{1}{2}\gamma \sin 2\theta, \tag{3}$$

where Δl is the change about l, θ is the angle between FBG axes and the torsion beam axes.

2.2. Principle of Torsion Beam Strain Sensing

When the temperature is stable, the Bragg wavelength shift $\Delta\lambda$ can be expressed as[4]

$$\frac{\Delta\lambda}{\lambda_0} = \eta_\varepsilon \varepsilon, \tag{4}$$

where λ_0 is the original Bragg wavelength (the center wavelength), η_ε is a constant in reference to the fiber photoelastic coefficient, fiber Poisson ratio and the effective refractive index of the fiber core. ε is the strain of FBG, it can be directly or indirectly produced by applying lateral stress or longitudinal stress in the applications. From formula above, the relationship between the angle displacemen φ, the torque $\mathbf{M}_t$ and the FBG wavelength shift $\Delta\lambda$ can be expressed as

$$\varphi = \frac{4L_0}{\eta_\varepsilon \lambda_0 d \sin 2\theta} \Delta\lambda = \kappa_\varphi \Delta\lambda , \qquad \text{for} \quad d<<L_0 \tag{5}$$

$$M_t = \frac{4GI_p}{\eta_\varepsilon \lambda_0 d \sin 2\theta} \Delta\lambda = \kappa_M \Delta\lambda , \qquad \text{for} \quad d<<L_0 \tag{6}$$

where κ_φ and κ_M are proportional factors, the photoelastic effect is ignored.

3. EXPERIMENT

Figure 2 shows the configuration of the FBG sensing experiment based on the torsion beam. The FBG's center wavelength λ_0=1562.48nm, and l=1.2cm, z_c=3.6cm, $\theta \approx 10^\circ$. The resolution of a commercial optical spectrum analyzer (OSA) is 0.2 nm. Light from a Broadband source (BBS) is coupled via a 3dB fiber coupler into the sensor. IMG is index matching oil by which the undesirable reflection is suppressed.

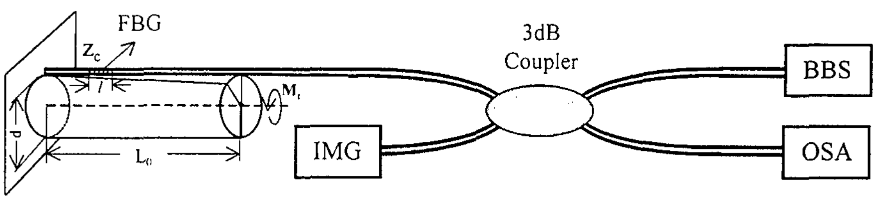

Fig.2 The configuration of the FBG sensing experiment based on the torsion beam.

Figure3 shows the shifts of the transmission intensity and the FWHM do not change in the range of 7 nm. Thus we can consider that there is no chirping within wavelength ranges above mention.

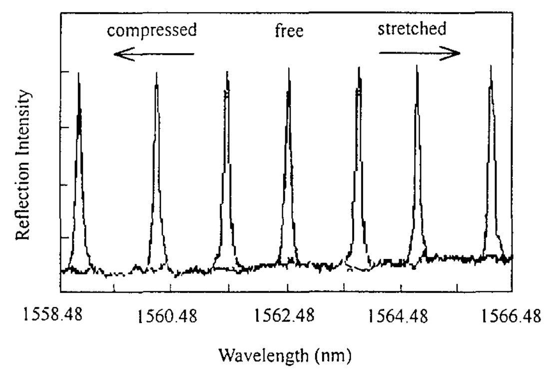

Fig.3. Bragg reflection wavelength shift as a function of intensity.

Figure4 shows the Bragg wavelength shift as a function of the torsional angle and the torque. The maximum shifts of approximately -3.4nm and 3.6nm are obtained toward shorter and longer wavelengths in our experiment, respectively. It is clear to see that the Bragg wavelength can be linearly changed with the torsional angle and the torque. The fitting straight lines are respectively: λ=0.0867φ+1562.5 (nm/degree), λ=6.27 M_t+1562.5(nm/Nm), and their linear goodness-of-fit are 0.9979. These indicate that the linearity is very good. This relationship can be rewritten as φ=11.534$\Delta\lambda$ (degree/nm), M_t=0.1595$\Delta\lambda$ (Nm/nm). These mean the sensing sensitivity of the torsional angle is estimated to be 11.534 degree/nm and that of the torque is to be 0.1595 Nm/nm at around 1.55 μm for single mode fiber, respectively.

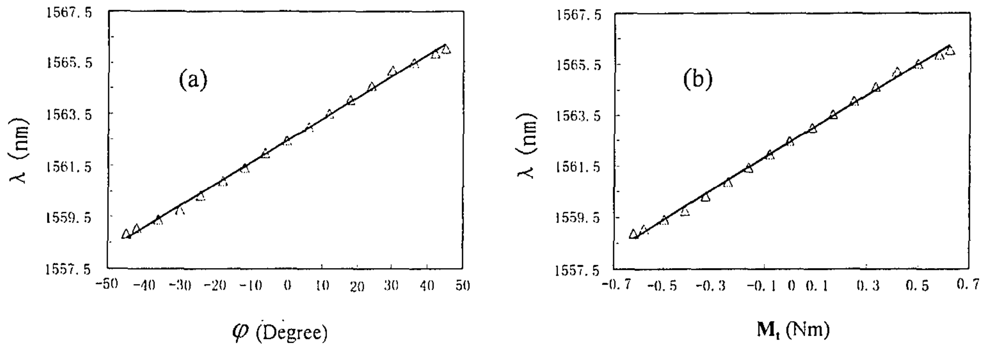

Fig.4. Bragg reflection wavelength shift $\Delta\lambda$ as a function of the torsional angle φ and the torque $\mathbf{M}_t$.

With our grating sensor, adjusting beyond the wavelength shift range from -3.4 nm to +3.6 nm was possible, however, the gratings then were susceptible to chirp and to damage. These indicate that there is a certain changing range for linearly no-chirped response the torsional angle on condition that the torsional strain of torsion beam is very small.

According to the relative parameters of the formula (5) and (6), the sensing sensitivity κ_φ and κ_M can be obtained. κ_φ is 8.643 degree/nm and κ_M is 0.1159 Nm/nm for calculating theoretical values, and κ_φ is 11.534 degree/nm and κ_M is 0.1595 Nm/nm for fitting experimental values in the range between -45° and +45°, respectively. Therefore, the revise factors χ_φ and χ_M should be introduced for application. It can be expressed as

$$\varphi = \chi_\varphi \kappa_\varphi \Delta\lambda \tag{7}$$

$$M_p = \chi_M \kappa_M \Delta\lambda \tag{8}$$

While χ_φ =1.33 and χ_M =1.37, the fitting experimental values are in agreement with the calculated theoretical values. If the structure in figure 2 is improved, it is possible to measure and control some parameters such as the velocity and the volume of flow, the intensity, the rigidity and stability of the tectonic elements[5], etc.

4. CONCLUSIONS

We have designed and realized a novel fiber grating sensing technology based on the torsion beam. The Bragg wavelength shift is linear to the torsional angle and the torque and there is no-chirped between -45° and +45°. The experimental results basically accord with theoretical analyses.

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